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Gestational weight gain and the risk of offspring obesity at 10 and 16 years: a prospective cohort study in low-income women

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Abstract

Objective—To study the association between gestational weight gain (GWG) and offspring obesity risk at ages chosen to approximate prepuberty (10 years) and postpuberty (16 years).

Design—Prospective pregnancy cohort.

Setting—Pittsburgh, PA, USA.

Sample—Low-income pregnant women ($n = 514$) receiving prenatal care at an obstetric residency clinic and their singleton offspring.

Methods—Gestational weight gain was classified based on maternal GWG-for-gestational-age Z-score charts and was modelled using flexible spline terms in modified multivariable Poisson regression models.

Main outcome measures—Obesity at 10 or 16 years, defined as body mass index (BMI) Z-scores $\geq$ 95th centile of the 2000 CDC references, based on measured height and weight.

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Disclosure of interests

None.

Contribution to authorship

JD analysed and interpreted data and wrote the manuscript. JD, CE, ND, MB, SA and LB designed the research, aided in the analytic strategy and in interpretation of the data, provided critical revision of the manuscript for important intellectual content, and read and approved the final manuscript.

Details of ethics approval

This secondary analysis was approved by the Institutional Review Board of the University of Pittsburgh on 9 August 2012 (Reference Number: PRO12070603).

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. Characteristics of the study sample overall and by offspring obesity at 16 years.

Results—The prevalence of offspring obesity was 20% at 10 years and 22% at 16 years. In the overall sample, the risk of offspring obesity at 10 and 16 years increased when GWG exceeded a GWG Z-score of 0 SD (equivalent to 30 kg at 40 weeks); but for gains below a Z-score of 0 SD there was no relationship with child obesity risk. The association between GWG and offspring obesity varied by prepregnancy BMI. Among mothers with a pregravid BMI <25 kg/m², the risk of offspring obesity increased when GWG Z-score exceeded 0 SD, yet among overweight women (BMI ≥ 25 kg/m²), there was no association between GWG Z-scores and offspring obesity risk.

Conclusions—Among lean women, higher GWG may have lasting effects on offspring obesity risk.

Keywords

Adolescents; gestational weight gain; obesity; prenatal factors

Introduction

Nearly one in six US adolescents aged 12–19 years is obese [body mass index (BMI) ≥ 95th centile of the CDC 2000 growth reference].¹ Rates of obesity are particularly elevated among low-income and minority adolescents. Obese adolescents are at higher risk of depression² and substance use³ than leaner adolescents. They are also more likely to be obese in adulthood and suffer from obesity-related comorbidities.^{4,5} The aetiology of obesity is probably multifactorial, resulting from complex interactions among excess caloric consumption, lack of physical activity, inadequate sleep, and gene–environment interactions.⁶

In utero insults such as excessive gestational weight gain (GWG) may program fetal metabolism and pancreatic β cell number and function,^{7,8} impacting offspring fat storage and metabolism early in life. However, these effects may become most evident after developmental periods such as puberty, when children are expected to gain fat^{9–11} to provide a reserve of energy for future periods of physiological and evolutionary importance, such as pregnancy.^{12,13} Excessive GWG has been associated with child obesity risk over a range of ages,¹⁴ but relatively few studies have addressed offspring obesity before and after puberty. Our objective was to estimate the association between GWG and the risk of offspring obesity at ages that approximate prepuberty (10 years) and post-puberty (16 years).

Methods

Study population and measures

We used secondary data from a prospective cohort of pregnant women and their children that was originally designed to investigate the influence of prenatal substance use on child growth and development.¹⁵ At an urban prenatal clinic at Magee-Women's Hospital (Pittsburgh, PA; 1982–85), a sequential sample of 1600 women ≥ 18 years old and <26 weeks pregnant was approached, and 85% agreed to participate. From this sample, women were selected into one of two cohorts based on first-trimester alcohol or marijuana use. Each cohort included women using alcohol or marijuana across the spectrum of use as well as women who abstained. Sampling was conducted with replacement (60% overlap) and the

combined cohort ($n = 829$) was used for this analysis.¹⁵ Women were interviewed at initial screening [mean 18.8 weeks gestation, standard deviation (SD) 2.7], and with their offspring at delivery and at 10- and 16-year follow-up assessments (mean 10.5 years, 0.5 SD; 16.9 years, 0.7 SD, respectively). Further details of the core study design and methodology are available elsewhere.¹⁶ The original study was approved by the Institutional Review Boards of Magee-Women's Hospital and University of Pittsburgh. Written, informed consent was obtained for each study phase.

At birth, 763 women and their liveborn singleton infants were eligible for follow-up assessment. Of these, 90% and 85% were interviewed at the 10- and 16-year follow-up visits, respectively. We excluded mother-child pairs with missing maternal data for prepregnancy BMI or GWG ($n = 20$), implausible GWG Z-scores (< -5 SD, $n = 2$), and those for whom child weight and height were unavailable at either the 10- or 16-year assessments ($n = 227$). A total of 514 mother-child pairs were analysed. Compared to the excluded group, the final analytic sample had a higher proportion of women who were of black race and a higher proportion of women who did not abstain from marijuana throughout pregnancy. There were no differences by other variables, including sociodemographic characteristics, other substance use, mental health, or measures of adolescent health behaviours or pubertal status (data not shown).

Total pregnancy weight gain was self-reported at delivery. GWG was classified using maternal weight gain Z-score charts standardised for prepregnancy BMI and gestational age.¹⁷ We used normal weight gain Z-score charts for all women because these charts eliminate any confounding by gestational age while also allowing us to evaluate effect modification by maternal BMI. Maternal prepregnancy BMI (weight [kg]/height[m]²) was based on prepregnancy weight and height that were self-reported at the first study visit.

Our primary outcomes were child obesity at 10 or 16 years, which we defined based on age- and sex-adjusted BMI Z-scores according to the CDC growth references.¹⁸ Offspring weight and height assessments were measured by trained study nurses using a calibrated scale at 10 and 16 years. All Z-score calculations fell within a predetermined plausible range (> -5 to < 5).

Covariates

Data were available for a number of maternal characteristics at first prenatal study visit. Maternal race, age, marital status, employment status, monthly household income, education level, parity and substance use, as well as psychological, social and environmental factors were self-reported at each prenatal visit. Maternal first-trimester uses of tobacco, alcohol and marijuana were categorised using published classifications.¹⁹ We also studied the pattern of alcohol or marijuana use over the course of pregnancy (abstained throughout pregnancy; abstained after first trimester; did not abstain after first trimester). Scores 75th centile on the Center for Epidemiologic Studies Depression Scale²⁰ and the State-Trait Personality Inventory²¹ were considered elevated levels of maternal depression and anxiety, respectively, during pregnancy. A social support factor score < 25 th centile defined low maternal social support.²² We additionally used measures of postpartum depression, anxiety,

substance use, maternal obesity, and maternal weight change from prepregnancy to 10 or 16 years postpartum.

Child data for a variety of characteristics were collected at the 10- and 16-year follow-up visits. We classified children as having early pubertal development at 10 and 16 years if they answered ‘much earlier’ or ‘somewhat earlier’ to one item from the Petersen Development Scale:²³ ‘Do you think your development is any earlier or later than most other boys/girls your age?’ All other responses were classified as ‘same or later’. Also at 16 years, adolescents self-reported their pubertal status using the full Petersen Development Scale²³ and were classified as ‘advanced puberty/post-pubertal’ or ‘prepubescent/early puberty’. Diagnosis of major depression in the adolescent was assessed using the Diagnostic Interview Schedule IV²⁴ and anxiety was measured using the Children’s Manifest Anxiety Scale.²⁵ Adolescents’ involvement in sports, hobbies, responsibility for chores, and number of close friends was assessed by maternal report using the Child Behaviour Checklist.²⁶ Validated measures of adolescent alcohol, marijuana and tobacco use²⁷ were used, and use of each was classified as abstained or ever used.

Statistical analysis

Differences in categorical maternal characteristics at <26 weeks by offspring obesity status at 10 and 16 years of age were tested with Pearson chi-square tests. The relative risks (RR) and 95% confidence intervals (95% CI) for the association between GWG Z-score and offspring obesity at 10 and 16 years were estimated using multivariable modified Poisson regression with a robust variance estimator.²⁸ There was a non-linear relation between GWG and the log of obesity at 16 years; we therefore modelled GWG Z-score using restricted cubic splines with three knots at Z-scores of – 1.60, – 0.20 and 1.10.²⁹ We also used the tertiles of the distribution to categorise GWG Z-scores into three groups.

We used theory-based causal diagrams³⁰ to guide our choice of potential confounders. These included prenatal factors (pregnancy BMI, maternal age, maternal race, parity, first-trimester income, maternal education, maternal mental health, prenatal substance use and the pattern of prenatal substance use). We also considered several postnatal factors at 10 and 16 years of follow up as potential confounders because they may represent aspects of the shared maternal–child environment. Potential confounders included child sex, child mental health, child substance use and involvement in sports or hobbies. Factors that are likely to lie on the causal path (birth weight, gestational age, maternal postpartum obesity and change in postpartum weight) were not considered potential confounders.³¹ We performed a sensitivity analysis by including pubertal status of the offspring as a potential confounder because it may or may not³² lie on the causal path. Our goal was to fit a parsimonious regression model and remove potential confounders if their inclusion did not satisfy our *a priori* change-in-estimate criterion (10% change in the risk ratio). Maternal prepregnancy BMI and first-trimester tobacco cigarette use met our definition of confounding. A likelihood ratio test ($\alpha = 0.10$) was used to test for effect modification on the multiplicative scale by race, prepregnancy overweight, postpartum obesity, change in postpartum BMI, maternal depression, anxiety, substance use or offspring sex. Inverse probability sample weights were used in the sensitivity analyses to account for the sampling

scheme.^{33,34} All analyses were conducted using STATA software, version 11 (College Station, TX, USA).

Results

At study enrolment, women were an average of 23 (SD 3.8) years old, and most were unmarried (68%), with a reported household income of <\$400 per month (61%). Fifty-nine percent of women had a normal prepregnancy BMI, 13% were underweight, while 19% and 10% were overweight or obese, respectively (see Supplementary material, Table S1). Slightly more than half the sample was black, slightly more than half of the women were parous, and only 13% had more than 12 years of education. Alcohol or marijuana use was common in the first trimester. On average, women in our sample gained 14.4 (SD 5.68) kg during pregnancy. At age 10, 78% of the offspring reported pubertal development that was similar to their peers, whereas the remainder reported earlier development. At 16 years, 89% of adolescents reported an advanced or postpubertal stage.

At 10 and 16 years, 20% and 22% of offspring were obese, respectively, and 69% of those who were obese at 10 years remained obese at 16 years. Women with a higher prepregnancy BMI were more likely than leaner women to have an obese child at either 10 or 16 years. As compared with their counterparts, white women and women who reported more frequent tobacco and marijuana use in the first trimester were more likely to have an obese 16-year-old. There were no differences in the likelihood of obesity by adolescent pubertal status, depression or substance use. Mothers who were obese at 16 years postpartum and mothers with 4.5 to <13.6 kg (10 to <16 lb) of postpartum weight gain were more likely to have an obese 16-year-old.

In bivariate analyses, the prevalence of child obesity was not significantly different by GWG Z-score tertile at 10 or 16 years. After adjusting for prepregnancy BMI, first-trimester maternal smoking status, the risk of child obesity at 16 years increased significantly from GWG Z-scores – 1.0 SD to 1.5 SD (Figure 1). A GWG Z-score of + 1.5 SD was associated with a 1.81-fold increase in the risk of child obesity at age 16 compared with GWG Z-score of 0 SD (Table 1). GWG Z-scores of + 1.5 SD and 0 SD correspond to a total GWG at 40 weeks of gestation of approximately 27–30 kg, in normal weight. Trends were similar with child obesity at 10 years, but did not reach statistical significance.

The association between GWG and offspring obesity risk at 10 and 16 years was modified by prepregnancy BMI. Among mothers who were lean before pregnancy (BMI <25 kg/m²), the risk of offspring obesity at 10 years (Figure 2A) and 16 years (Figure 2B) increased beginning at a GWG Z-score of 0 SD (16.4 kg at 40 weeks of gestation). After adjusting for confounders, lean women with GWG Z-scores of + 0.5 SD (19.5 kg at 40 weeks), + 1.0 SD (23.0 kg), and + 1.5 SD (26.8 kg) had 28%, 74% and 240% increases in the risk of having a child who was obese at 16 years, respectively, compared with women with GWG Z-scores of 0 SD (Table 2). Among lean women, the association between very low GWG and risk of offspring obesity at 16 years was not statistically significant. Results were similar for offspring obesity at 10 years.

In contrast, among women who were overweight before pregnancy (BMI ≥ 25 kg/m²), there appeared to be an increase in the adjusted risk of offspring obesity at 16 years as GWG Z-score rose to 0 SD (15.8 kg at 40 weeks of gestation) and levelled off thereafter (Figure 2C, D); however, these results did not reach statistical significance (Table 2).

Results did not additionally vary by race, postpartum obesity, a change in postpartum weight or BMI, maternal depression, anxiety, alcohol, marijuana, or tobacco smoking, or sex of the offspring. When we limited models to women who stopped using alcohol or marijuana after the first trimester, similar results were found (data not shown). Results were also similar after adjusting for additional confounders, including pubertal status at 10 and 16 years, and after applying inverse probability sample weights.

Discussion

Main findings

We found that among lean women, higher GWG was related to higher risk of offspring obesity at 10 and 16 years after adjustment for prenatal factors. The present study builds upon our earlier work, which showed positive associations between GWG and obesogenic infant growth patterns³⁵ and offspring obesity at 36 months,³⁶ suggesting that an association persists into adolescence.

Strengths and limitations

Our prospective cohort study was not originally designed to evaluate research on GWG and childhood obesity, resulting in several limitations. Our findings in this low-income sample of women pregnant in the 1980s – a majority of whom used substances early in pregnancy – may not be generalisable to other populations. However, it is notable that our findings were consistent when we excluded heavy substance users. Substance use in pregnancy remains common in the USA today,³⁷ and we feel that our ability to adjust for substance use is a strength. The parent study evaluated children at 10 and 16 years and did not collect data on the age of pubertal onset. Although most children at age 16 were postpubertal, we ideally would have studied the association between GWG and offspring obesity in a group of children both before and after confirmed puberty. Additionally, although we considered breastfeeding, prenatal and postnatal maternal substance use and mental health status, socioeconomic factors, and maternal social support as confounders in our analysis, unmeasured variables such as child's diet and physical activity may have biased our results. Maternal weight data were recalled, but its collection proximal to the time period of interest lessens the likelihood of bias.

Interpretation

We know of only one study of maternal GWG and offspring obesity that included adolescent data and reported findings at ages likely to represent pre- and postpuberty.³⁸ Rooney et al. followed 532 offspring of women who gained in excess of the 1990 and Institute of Medicine/GWG guidelines and compared them with those gaining within the recommended ranges. They found that women with excessive GWG had children with significant increases in the odds of offspring overweight (BMI ≥ 85 th percentile of the CDC

growth curves) at 9–14 years and obesity (BMI ≥ 30.0 kg/m²) at 18–20 years as compared with those gaining within the recommended ranges, after adjustment for maternal marital status at delivery, insurance status at birth, and child gender. An important limitation to this study is that these results were not adjusted for prepregnancy BMI, a strong confounder, so findings may be biased away from the null.

Studies of offspring near to the time of puberty tend to support a positive association between GWG and offspring weight or fat mass.^{39–41} Oken et al.⁴⁰ studied 11 994 US 9- to 14-year-old offspring and their mothers. Pubertal development varied across the sample, with 47% pre- or early-puberty (Tanner Stage I or II). Every 5 lb (2.3 kg) increase in GWG was associated with a 9% increase in the odds of child obesity (95% CI 1.06–1.13) after adjusting for prepregnancy BMI, maternal age, smoking in pregnancy, household income and paternal education, gestational age, and child characteristics including race/ethnicity, sex, age and Tanner stage of pubertal development. Unlike our study, this study used child self-reported weight and height, which may be prone to misreporting, especially during growth spurts.^{42,43} GWG has also been positively related to BMI, waist circumference, and fat mass in one study of 9-year-old British children,⁴¹ but not in another.³⁹ Among 16-year-old offspring, positive associations between GWG and waist circumference⁴⁴ were reported in Swedish and Finnish samples. Our results and most previous studies contradict findings by Stuebe et al.,⁴⁵ which suggested that low GWG increased the risk of offspring obesity in 18-year-old daughters of women enrolled in the Nurses' Health Study II.

We found that the risk of adolescent obesity was flat until about 16 kg and then rose among lean women, but that no association was observed among overweight women. We are not aware of previous studies that examined nonlinear relationships between GWG and adolescent obesity risk separately by maternal BMI. However, several research groups have reported that excessive GWG increases the risk of adolescent obesity for children of lean and overweight women to a similar extent.^{40,46}

Gestational weight gain may directly impact offspring adiposity through a number of developmental programming mechanisms.⁴⁷ Offspring exposed to excessive GWG, and so to higher insulin, may be predisposed to fat accrual through altered programming of the fetal pancreas^{7,8} or modified neural circuitry,⁴⁸ leading to altered appetite regulation and a failure to limit energy reserves.⁴⁹ We hypothesised that in later life, offspring who were conditioned *in utero* may have an intrinsic vigilance against weight loss during biologically important growth periods such as puberty. We did not observe a major difference in the relationship between GWG and offspring obesity in the pre- and postpubertal periods, but this may be because most of the children who were obese at 10 years were also obese at 16 years. Alternatively, our use of BMI rather than a direct measure of fat mass may not be specific enough to capture key differences in body composition and fat distribution across these two periods.

The GWG–child obesity association that we and others noted may not be causal, but rather may reflect shared familial or environmental characteristics in adolescence such as an obesogenic environment. Lawlor et al.⁴⁶ attempted to control for shared factors in a sibling analysis of 146 894 Swedish 18-year-old men. The authors analysed data conventionally

(controlling for measured confounders) and using a sibling analysis to additionally control for unmeasured familial factors. The study found that among overweight women, GWG was positively associated with offspring BMI in the conventional analysis and was strengthened in the sibling analysis. For lean women, a positive association between GWG and offspring BMI was observed in the conventional analysis, but not with adjustment for shared familial factors in the sibling analysis. These results suggest that an association between GWG and offspring BMI may be largely driven by shared familial factors among lean women. We lacked sibling data and instead used maternal postpartum BMI and weight change as a proxy for an obesogenic environment. We did not find evidence that the GWG–adolescent obesity relationship varied by levels of maternal postpartum weight or weight change.

Conclusion

Our results support the growing body of evidence suggesting that GWG is positively associated with adolescent obesity risk among lean women. Randomised trials are needed to test the causality of this association.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgements

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References

1. Ogden CL, Carroll MD, Kit BK, Flegal KM. Prevalence of childhood and adult obesity in the United States, 2011–2012. *JAMA*. 2014; 311:806–814. [PubMed: 24570244]
2. Hoare E, Skouteris H, Fuller-Tyszkiewicz M, Millar L, Allender S. Associations between obesogenic risk factors and depression among adolescents: a systematic review. *Obes Rev*. 2014; 15:40–51. [PubMed: 23980942]
3. Farhat T, Iannotti RJ, Simons-Morton BG. Overweight, obesity, youth, and health-risk behaviors. *Am J Prev Med*. 2010; 38:258–267. [PubMed: 20171527]
4. Freedman DS, Khan LK, Dietz WH, Srinivasan SR, Berenson GS. Relationship of childhood obesity to coronary heart disease risk factors in adulthood: the Bogalusa Heart Study. *Pediatrics*. 2001; 108:712–718. [PubMed: 11533341]
5. Must A, Jacques PF, Dallal GE, Bajema CJ, Dietz WH. Long-term morbidity and mortality of overweight adolescents. A follow-up of the Harvard Growth Study of 1922 to 1935. *N Engl J Med*. 1992; 327:1350–1355. [PubMed: 1406836]
6. Miller J, Rosenbloom A, Silverstein J. Childhood obesity. *J Clin Endocrinol Metab*. 2004; 89:4211–4218. [PubMed: 15356008]
7. Ford SP, Zhang L, Zhu M, Miller MM, Smith DT, Hess BW, et al. Maternal obesity accelerates fetal pancreatic beta-cell but not alpha-cell development in sheep: prenatal consequences. *Am J Physiol Regul Integr Comp Physiol*. 2009; 297:R835–R843. [PubMed: 19605766]

8. Zhang L, Long NM, Hein SM, Ma Y, Nathanielsz PW, Ford SP. Maternal obesity in ewes results in reduced fetal pancreatic beta-cell numbers in late gestation and decreased circulating insulin concentration at term. *Domest Anim Endocrinol*. 2011; 40:30–39. [PubMed: 20933362]
9. Dietz WH. Critical periods in childhood for the development of obesity. *Am J Clin Nutr*. 1994; 59:955–959. [PubMed: 8172099]
10. Dietz WH. Periods of risk in childhood for the development of adult obesity—what do we need to learn? *J Nutr*. 1997; 127:1884S–1886S. [PubMed: 9278575]
11. Adair LS. Child and adolescent obesity: epidemiology and developmental perspectives. *Physiol Behav*. 2008; 94:8–16. [PubMed: 18191968]
12. Norgan NG. The beneficial effects of body fat and adipose tissue in humans. *Int J Obes Relat Metab Disord*. 1997; 21:738–746. [PubMed: 9376885]
13. Zafon C. Oscillations in total body fat content through life: an evolutionary perspective. *Obes Rev*. 2007; 8:525–530. [PubMed: 17949356]
14. Nehring I, Lehmann S, von Kries R. Gestational weight gain in accordance to the IOM/NRC criteria and the risk for childhood overweight: a meta-analysis. *Pediatr Obes*. 2012; 8:218–224. [PubMed: 23172639]
15. Day NL, Richardson GA, Geva D, Robles N. Alcohol, marijuana, and tobacco: effects of prenatal exposure on offspring growth and morphology at age six. *Alcohol Clin Exp Res*. 1994; 18:786–794. [PubMed: 7526725]
16. Day NL, Jasperse D, Richardson G, Robles N, Sambamoorthi U, Taylor P, et al. Prenatal exposure to alcohol: effect on infant growth and morphologic characteristics. *Pediatrics*. 1989; 84:536–541. [PubMed: 2771556]
17. Hutcheon JA, Platt RW, Abrams B, Himes KP, Simhan HN, Bodnar LM. A weight-gain-for-gestational-age z score chart for the assessment of maternal weight gain in pregnancy. *Am J Clin Nutr*. 2013; 97:1062–1067. [PubMed: 23466397]
18. Kuczmarski RJ, Ogden CL, Grummer-Strawn LM, Flegal KM, Guo SS, Wei R, et al. CDC growth charts: United States. *Adv Data*. 2000; 314:1–27. [PubMed: 11183293]
19. Day NL, Leech SL, Richardson GA, Cornelius MD, Robles N, Larkby C. Prenatal alcohol exposure predicts continued deficits in offspring size at 14 years of age. *Alcohol Clin Exp Res*. 2002; 26:1584–1591. [PubMed: 12394293]
20. Radloff L. CES-D. The CES-D scale: a self-report depression scale for research in the general population. *Appl Psychol Meas*. 1977; 1:385–401.
21. Spielberger, CD. STPI. Center for Research in Behavioral Medicine and Health Psychology. Tampa: PCD 4118G, University of South Florida; 1979. Preliminary manual for the State-Trait Personality Inventory (STPI).
22. Goldschmidt L, Richardson GA, Stoffer DS, Geva D, Day NL. Prenatal alcohol exposure and academic achievement at age six: a nonlinear fit. *Alcohol Clin Exp Res*. 1996; 20:763–770. [PubMed: 8800397]
23. Petersen AC, Crockett L, Richards M, Boxer A. A self-report measure of pubertal status: reliability, validity, and initial norms. *J Youth Adolesc*. 1988; 17:117–133. [PubMed: 24277579]
24. Robins, LN.; Cottler, LB.; Bucholz, KK.; Compton, WM.; North, CS.; Rourke, KM. Diagnostic Interview Schedule for DSM-IV. St. Louis, MO: Washington University School of Medicine, Department of Psychiatry; 2000.
25. Reynolds CR, Richmond BO. What I think and feel: a revised measure of children's manifest anxiety. *J Abnorm Child Psychol*. 1978; 6:271–280. [PubMed: 670592]
26. Achenbach, T. Manual for the Child Behavioral Checklist/4-18 and 1991 Profile. Burlington: University of Vermont, Department of Psychiatry; 1991.
27. Day NL, Goldschmidt L, Thomas CA. Prenatal marijuana exposure contributes to the prediction of marijuana use at age 14. *Addiction*. 2006; 101:1313–1322. [PubMed: 16911731]
28. Zou G. A modified poisson regression approach to prospective studies with binary data. *Am J Epidemiol*. 2004; 159:702–706. [PubMed: 15033648]
29. Harrell, FE. Regression Modeling Strategies: With Applications to Linear Models, Logistic Regression, and Survival Analysis. Heidelberg: Springer; 2001.

30. Greenland S, Pearl J, Robins JM. Causal diagrams for epidemiologic research. *Epidemiology*. 1999; 10:37–48. [PubMed: 9888278]
31. Cole SR, Platt RW, Schisterman EF, Chu H, Westreich D, Richardson D, et al. Illustrating bias due to conditioning on a collider. *Int J Epidemiol*. 2010; 39:417–420. [PubMed: 19926667]
32. Boynton-Jarrett R, Rich-Edwards J, Fredman L, Hibert EL, Michels KB, Forman MR, et al. Gestational weight gain and daughter's age at menarche. *J Womens Health (Larchmt)*. 2011; 20:1193–1200. [PubMed: 21711153]
33. Hernan MA, Hernandez-Diaz S, Robins JM. A structural approach to selection bias. *Epidemiology*. 2004; 15:615–625. [PubMed: 15308962]
34. Vanderwerker, LC.; Day, NL.; Baker, CE.; Richardson, GA.; Stone, RA. Unpublished doctoral dissertation. Pittsburgh: University of Pittsburgh; 2003. Depression in children: A comparison of mother and child reports.
35. Diesel, JC.; Eckhardt, CL.; Day, NL.; Brooks, MM.; Arslanian, SA.; Bodnar, LM. Gestational Weight Gain in Association with Early Childhood Weight Gain and Obesity. Bpston, MA: Society for Paediatric and Perinatal Epidemiology (SPER); 2013.
36. Diesel JC, Eckhardt CL, Day NL, Brooks MM, Arslanian SA, Bodnar LM. Is gestational weight gain associated with offspring obesity at 36 months? *Pediatr Obes*. 2014 [Epub ahead of print].
37. Substance Abuse and Mental Health Services Administration OoAS. The NSDUH Report: Substance Use among Women During Pregnancy and Following Childbirth. 2009 2009.
38. Rooney BL, Mathiason MA, Schauburger CW. Predictors of obesity in childhood, adolescence, and adulthood in a birth cohort. *Matern Child Health J*. 2011; 15:1166–1175. [PubMed: 20927643]
39. Gale CR, Javaid MK, Robinson SM, Law CM, Godfrey KM, Cooper C. Maternal size in pregnancy and body composition in children. *J Clin Endocrinol Metab*. 2007; 92:3904–3911. [PubMed: 17684051]
40. Oken E, Rifas-Shiman SL, Field AE, Frazier AL, Gillman MW. Maternal gestational weight gain and offspring weight in adolescence. *Obstet Gynecol*. 2008; 112:999–1006. [PubMed: 18978098]
41. Fraser A, Tilling K, Macdonald-Wallis C, Sattar N, Brion MJ, Benfield L, et al. Association of maternal weight gain in pregnancy with offspring obesity and metabolic and vascular traits in childhood. *Circulation*. 2010; 121:2557–2564. [PubMed: 20516377]
42. Sherry B, Jefferds ME, Grummer-Strawn LM. Accuracy of adolescent self-report of height and weight in assessing overweight status: a literature review. *Arch Pediatr Adolesc Med*. 2007; 161:1154–1161. [PubMed: 18056560]
43. Brettschneider AK, Rosario AS, Ellert U. Validity and predictors of BMI derived from self-reported height and weight among 11- to 17-year-old German adolescents from the KiGGS study. *BMC Res Notes*. 2011; 4:414. [PubMed: 22005143]
44. Laitinen J, Jaaskelainen A, Hartikainen AL, Sovio U, Vaarasmaki M, Pouta A, et al. Maternal weight gain during the first half of pregnancy and offspring obesity at 16 years: a prospective cohort study. *BJOG*. 2012; 119:716–723. [PubMed: 22489762]
45. Stuebe AM, Forman MR, Michels KB. Maternal-recalled gestational weight gain, pre-pregnancy body mass index, and obesity in the daughter. *Int J Obes (Lond)*. 2009; 33:743–752. [PubMed: 19528964]
46. Lawlor DA, Lichtenstein P, Fraser A, Langstrom N. Does maternal weight gain in pregnancy have long-term effects on offspring adiposity? A sibling study in a prospective cohort of 146,894 men from 136,050 families. *Am J Clin Nutr*. 2011; 94:142–148. [PubMed: 21562086]
47. Ford SP, Tuersunjiang N. Maternal obesity: how big an impact does it have on offspring prenatally and during postnatal life? *Exp Rev Endocrinol Metab*. 2013; 8:261–273.
48. Muhlhausler BS, Adam CL, McMillen IC. Maternal nutrition and the programming of obesity: the brain. *Organogenesis*. 2008; 4:144–152. [PubMed: 19279726]
49. Long NM, George LA, Uthlaut AB, Smith DT, Nijland MJ, Nathanielsz PW, et al. Maternal obesity and increased nutrient intake before and during gestation in the ewe results in altered growth, adiposity, and glucose tolerance in adult offspring. *J Anim Sci*. 2010; 88:3546–3553. [PubMed: 20622177]

Figure 1.

Adjusted predicted probability of offspring obesity at 10 or 16 years by GWG z -score using restricted cubic splines with knots at -1.60 , -0.20 , and 1.10 . [†]Adjusted for smoking in the first trimester (none; <0.5 packs/day; 0.5 to <1 packs/day; >1 packs/day). Panel A: Obesity at 10 years, overall ($n = 514$)[†]. Panel B: Obesity at 16 years, overall ($n = 514$)[†].

Figure 2.

Adjusted predicted probability of offspring obesity at 10 or 16 years by GWG z-score using restricted cubic splines with knots at -1.60 , -0.20 , and 1.10 . [†]Adjusted for smoking in the first trimester (none; <0.5 packs/day; 0.5 to <1 packs/day; >1 packs/day). Panel A: Obesity at 10 years, among mothers who were lean ($\text{BMI} < 25 \text{ kg/m}^2$) before pregnancy ($n = 369$)[†]. Panel B: Obesity at 16 years, among mothers who were lean ($\text{BMI} < 25 \text{ kg/m}^2$) before pregnancy ($n = 369$)[†]. Panel C: Obesity at 10 years, among mothers who were overweight ($\text{BMI} \geq 25 \text{ kg/m}^2$) before pregnancy ($n = 145$)[†]. Panel D: Obesity at 16 years, among mothers who were overweight ($\text{BMI} \geq 25 \text{ kg/m}^2$) before pregnancy ($n = 145$)[†].

Table 1

Association between gestational weight gain Z-score and risk of offspring obesity at 10 and 16 years, overall

GWG Z-score	Obesity at 10 years		Obesity at 16 years	
	Unadjusted RR (95% CI)	Adjusted RR* (95% CI)	Unadjusted RR (95% CI)	Adjusted RR* (95% CI)
Overall				
−2.0	0.99 (0.75–1.31)	0.83 (0.63–1.10)	0.97 (0.74–1.27)	0.82 (0.64–1.06)
−1.5	0.97 (0.80–1.18)	0.84 (0.69–1.03)	0.93 (0.77–1.12)	0.82 (0.68–0.98)
−1.0	0.95 (0.83–1.10)	0.87 (0.75–1.00)	0.91 (0.80–1.03)	0.83 (0.74–0.94)
−0.5	0.96 (0.88–1.05)	0.91 (0.83–1.00)	0.92 (0.85–0.99)	0.88 (0.82–0.95)
0	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
0.5	1.07 (0.94–1.23)	1.13 (0.99–1.30)	1.14 (1.02–1.28)	1.19 (1.06–1.34)
1.0	1.17 (0.87–1.57)	1.30 (0.96–1.76)	1.34 (1.04–1.73)	1.47 (1.14–1.89)
1.5	1.27 (0.80–2.01)	1.50 (0.94–2.40)	1.59 (1.07–2.35)	1.81 (1.21–2.68)

* Adjusted for prepregnancy BMI, smoking in the first trimester (none; <0.5 packs/day; 0.5 to <1 packs/day; >1 packs/day).

Table 2

Association between gestational weight gain Z-score and risk of offspring obesity at 10 and 16 years, stratified by maternal prepregnancy overweight

GWG Z-score	Obesity at 10 years		Obesity at 16 years	
	Unadjusted RR (95% CI)	Adjusted RR* (95% CI)	Unadjusted RR (95% CI)	Adjusted RR* (95% CI)
Lean (pregnancy BMI < 25 kg/m²)				
-2.0	1.42 (0.85–2.39)	1.45 (0.85–2.48)	1.29 (0.77–2.16)	1.31 (0.77–2.22)
-1.5	1.17 (0.83–1.64)	1.16 (0.82–1.65)	1.08 (0.78–1.52)	1.08 (0.77–1.53)
-1.0	0.99 (0.81–1.21)	0.97 (0.80–1.19)	0.95 (0.78–1.14)	0.93 (0.77–1.13)
-0.5	0.93 (0.83–1.03)	0.91 (0.82–1.01)	0.91 (0.83–1.00)	0.89 (0.81–0.98)
0	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
0.5	1.21 (1.03–1.43)	1.26 (1.07–1.48)	1.24 (1.07–1.43)	1.28 (1.11–1.47)
1.0	1.56 (1.09–2.24)	1.70 (1.18–2.45)	1.62 (1.18–2.23)	1.74 (1.26–2.40)
1.5	2.03 (1.15–3.57)	2.32 (1.31–4.11)	2.15 (1.30–3.55)	2.40 (1.45–3.97)
Overweight (pregnancy BMI ≥ 25 kg/m²)				
-2.0	0.76 (0.49–1.20)	0.74 (0.46–1.20)	0.78 (0.53–1.15)	0.73 (0.50–1.07)
-1.5	0.86 (0.63–1.19)	0.84 (0.60–1.18)	0.83 (0.64–1.09)	0.78 (0.60–1.03)
-1.0	0.96 (0.77–1.20)	0.94 (0.74–1.19)	0.89 (0.74–1.07)	0.84 (0.69–1.02)
-0.5	1.02 (0.88–1.18)	1.00 (0.86–1.16)	0.94 (0.84–1.06)	0.91 (0.81–1.04)
0	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
0.5	0.93 (0.74–1.16)	0.95 (0.75–1.20)	1.06 (0.89–1.27)	1.10 (0.90–1.34)
1.0	0.83 (0.51–1.37)	0.88 (0.53–1.47)	1.12 (0.76–1.66)	1.22 (0.79–1.89)
1.5	0.74 (0.34–1.61)	0.81 (0.37–1.80)	1.19 (0.64–2.19)	1.35 (0.68–2.67)

* Adjusted for prepregnancy BMI, smoking in the first trimester (none; <0.5 packs/day; 0.5 to <1 packs/day; >1 packs/day).